AEROSPACE RECOMMENDED PRACTICE

ARP4055™ REV. A

Issued 1988-01
Reaffirmed 2007-11
Stabilized 2020-12

Superseding ARP4055

Ground-Plane Microphone Configuration for
Propeller-Driven Light-Aircraft Noise Measurement

RATIONALE

This document is not used for certification. However, the technique used may be useful reference for researchers, and therefore it should be stabilized.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE A-21 Aircraft Noise Measurement Aviation Emission Modeling Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

TO PLACE A DOCUMENT ORDER: **Tel: 877-606-7323 (inside USA and Canada)**
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
SAE WEB ADDRESS: http://www.sae.org

For more information on this standard, visit
https://www.sae.org/standards/content/ARP4055A/

1. INTRODUCTION: When sound from a distant source is measured by use of a microphone located above the ground plane, the sound pressure level spectrum is distorted by reinforcements and cancellations resulting from interference between sound waves received directly from the source and those reflected from the ground. SAE AIR 1327[1] presents an analytical description of the interference effects between direct and reflected sound waves, for both discrete frequency and broadband noise sources. In particular, spectral irregularities caused by ground-reflection effects are shown to depend on the relative positions of the source, microphone and ground surface, and also on the wavelength (or frequency) of the sound arriving at the microphone. Wavelength is, in turn, dependent upon the local ambient temperature, which may vary from test to test. Additionally, the acoustical characteristics of the ground surface are important.

SAE AIR 1672B[2] describes several practical methods, developed by different organizations, for removing or minimizing ground reflection effects from engine and aircraft noise spectra measured using a microphone above a reflecting plane. The intent of all the procedures described in AIR 1672B is to obtain sound pressure levels equivalent to those that would have existed at the measurement location in an acoustic freefield, i.e., in a sound field where reflected waves are not present. Much of AIR 1672B is directed at the measurement of noise from aircraft engines under static test conditions, but Appendix D describes results of some flight experiments[3] conducted with a microphone mounted above a 2.4 m (8 ft) diameter wooden board.

[1,2,3] See references in Section 6.

1. INTRODUCTION: (Continued)

For most scientific and engineering purposes related to aircraft acoustics, a method to determine equivalent freefield sound pressure levels from flight test measurements is required. The majority of flight test noise measurements, including those made for certification and general airport noise-monitoring purposes, utilize microphones located some distance above the ground plane, and hence the data contain the effects of ground reflection interference. In particular, when the sound from a propeller-driven airplane is measured by a microphone mounted at the conventional height of 1.2 m, interference effects in the spectra are of major concern because the largest of the resultant reinforcement and cancellation effects often occur in the same frequency range as the fundamental and harmonics of the propeller blade-passing frequency (as well as the engine-firing frequency of piston engines). (See Appendix A.)

Many experimental arrangements to minimize ground reflection effects have been considered (see Refs. 3 to 13). Such arrangements have ranged from mounting microphones up to 10 m above the ground, to configurations where the microphone diaphragm was flush with the ground. With a 10 m microphone installation[2,3], the largest ground reflection interference effects are moved to frequencies lower than those associated with lesser heights (such as 1.2 m). However, cancellations and reinforcements at a height of 10 m may still distort measurements of the source noise in the frequency range of interest for propeller-driven aircraft. It would be necessary to measure at heights significantly greater than 10 m to minimize ground reflection effects in measured data from all propeller-driven aircraft. Since the logistics of taking measurements at heights above 10 m are difficult, a more practical installation is one where the microphone is close enough to the ground to ensure that the direct and ground-reflected sound waves are of equal amplitude and in phase (or nearly so) over the frequency range of interest. Under these conditions, the sound pressure at the location of the microphone is twice the corresponding freefield sound pressure, and the measured sound pressure level is six decibels (6.0 dB) greater than the freefield sound pressure level.

To achive full pressure-doubling, and hence a 6.0 dB reinforcement at all frequencies, it would be necessary to mount a microphone with its diaphragm flush with a large, acoustically "hard" and fully reflecting surface. Clearly, it would often be impractical to "bury" a microphone such that its diaphragm was in the same plane as a large, hard surface, and an alternative arrangement is necessary. Good results have been noted when the microphone is located in the center of a large convex inverted dish[8], or offset on a large circular board[2,3]. Another method is to lay the microphone flat on a convenient, large and acoustically hard ground surface, with its diaphragm vertical, such that interference effects occur at frequencies higher than with the microphone at heights of 1.2 or 10 m. However, although a simple arrangement, a microphone laying on the ground surface yields results that vary with the direction of sound incidence, the least variability only occurring when the aircraft flight track is always close to the plane of the microphone diaphragm.

[2,3,8] See references in Section 6.

1. INTRODUCTION: (Continued)

An arrangement that is practical, and which minimizes interference effects still further without exhibiting marked directional effects, is where the microphone is inverted so that its diaphragm is parallel to and only a small distance above a hard ground surface. Interference effects still occur, but if the separation between the diaphragm and the hard surface is sufficiently small, they are at frequencies above the frequency range of interest for propeller-driven aircraft.

Results from laboratory tests and other relevant investigations[3-13], have demonstrated that, for a "half-inch" pressure microphone, a separation of 7 mm between a hard ground surface and the microphone diaphragm is required to obtain measurements free from interference effects in the frequency range of interest.

When a hard reflecting surface is not available, noise measurements may still be made with an "inverted" microphone configuration, but the sound pressure levels will differ from those made over a hard surface, because of a reduction in the level of the reflected sound due to absorption, and variations in the effective position of the acoustic "ground" surface according to sound frequency. Greater consistency may be obtained by placing a heavy, hard and flat plate over the soft surface, and mounting the inverted microphone over the plate[7-14]. However, diffraction effects are introduced as a result of a discontinuity in acoustic impedance at the edge of the plate; for example, as described in Appendix D of Ref. 2.

Such edge diffraction effects may be minimized in two ways. First, the microphone may be located off center over a circular plate, such that diffraction effects are spread over a band of frequencies rather than being concentrated at one frequency which is a function of the radius of the plate. Second, the plate can be "bedded" flush with the surrounding terrain, so that most of the physical discontinuity at the edge may be minimized, although a change in acoustic impedance still remains. Other methods of reducing diffraction effects have been studied[8], but no configuration has yet been developed that exhibits no diffraction effects over the entire frequency range of interest.

It should be noted also that, with a microphone mounted very close to the ground, refraction and scattering caused by the micro-meteorological effects of turbulence, and wind or temperature gradients near the surface, can affect the measured sound pressure levels. However, such effects are normally only significant when sound waves propagate at very small angles relative to the ground plane. No evidence has been found of significant effects at propagation angles relevant to aircraft flyover noise measurements, provided the surface in the neighborhood of the microphone is painted white to minimize solar heating effects, and the windspeed is within normal limits for noise testing purposes.

[3-13,7-14,8] See references in Section 6.

1. INTRODUCTION: (Continued)

From the foregoing, a ground-plane microphone configuration is recommended in this ARP that will produce essentially undistorted measured spectra, from which a close approximation of propeller-driven aircraft freefield sound pressure levels may be obtained.

2. SCOPE: The scope of this ARP embraces the description of a configuration for a ground-plane microphone installation that may be used to determine sound pressure levels equivalent to those which would have been measured in an acoustic freefield at the microphone location. The one-third - octave-band center-frequency range over which equivalent freefield sound pressure levels may be obtained is from as low as 50 Hz to at least as high as 10,000 Hz.

The specific application of the measurement technique described in this ARP is the determination of the equivalent freefield sound pressure levels of the noise produced by propeller-driven light aircraft, in flight, for sound incidence angles within 30 degrees of the normal to the ground. For larger angles to the normal, additional adjustments may be necessary which are outside the scope of this ARP. Caution needs to be exercised, therefore, if the recommended configuration is used to measure the noise from aircraft other than those driven by propeller powerplants, in particular, when full spectral information is required (especially outside the range of 30 degrees to the normal to the ground surface), or when measurements of time-integrated noise descriptors are required.

3. RECOMMENDED GROUND-PLANE MICROPHONE INSTALLATION: The recommended ground-plane microphone installation employs a "half-inch" diameter microphone that has been designed to have its most uniform (i.e., flattest) frequency response in the pressure field of a closed cavity, e.g., a pressure or random-incidence-response capacitor microphone.

This pressure microphone, with its protective grid installed, shall be mounted in an inverted position so that the diaphragm is 7(+1,-0) mm above either an extensive acoustically hard surface or a circular metal plate, as illustrated in the sketch in Figure 1. With an inverted microphone above an extensive hard surface (e.g., concrete or well-sealed asphalt), which must be smooth and flat, the microphone shall be located at least 5 m from the edge of the surface. An area of at least 2 m radius around the microphone shall be painted white, to avoid local solar heating effects.

If not measuring over a hard surface, a white-painted circular metal plate, 0.4 m diameter and at least 2.5 mm thick, shall be "bedded" firmly and with its upper surface flush with the surrounding ground surface. The microphone shall be located at 3/4 radius from the center of the plate, in a direction normal to the intended flight track, as shown in Figure 1.

The 7 mm minimum separation is important, since a smaller gap will give rise to high-frequency amplifications, believed to be caused by microphone resonance effects[5]. Conversely, a gap significantly greater than 8 mm will cause ground reflections that will affect the high frequencies in the measured spectrum.

[5] See references in Section 6.

3. RECOMMENDED GROUND-PLANE MICROPHONE INSTALLATION: (Continued)

The separation between the microphone diaphragm and the face of the protective grid over the diaphragm should be obtained from the manufacturer's Instruction Manual for the specific type of microphone to be used, and slip gauges produced to ensure a repeatable "in-the-field" setting-up procedure. As an example, Figure 2 refers to a typical "half-inch" microphone, for which there is a 1.1 mm nominal separation between the diaphragm and the outer surface of the protective grid. From this dimension, a slip-gauge/bar control system is illustrated that will enable the recommended diaphragm-to-plate/surface dimension of 7(+1,-0) mm to be achieved.

For other microphone types, the dimensions of the gauges will need to differ according to any differences in the separation between the grid and the diaphragm.

NOTE: Sound pressure levels are normally measured when the mean steady wind speed is low, e.g., less than 12 knots (6 m/s) at 10 m or 10 knots (5 m/s) at 1.2 m. Close to the ground, the wind speed is significantly lower than at the normal position of windspeed measuring devices, and hence the use of a windscreen should not be required with any installation of an "inverted" ground-plane microphone.

4. ADJUSTMENT OF MEASURED SOUND PRESSURE LEVELS TO EQUIVALENT FREEFIELD SOUND PRESSURE LEVELS:

4.1 Measurement Over a Large Acoustically Hard Surface: When a half-inch-diameter pressure-microphone is inverted (as described in Section 3) above and close to a large, acoustically reflective surface, the measured sound pressure levels have a 6.0 dB reinforcement at all frequencies up to the frequency associated with the first interference cancellation. With a 7 mm gap between the microphone diaphragm and the reflecting surface, the first cancellation frequency will be above 10 kHz. Laboratory experiments[5] indicate that the one-third-octave-band sound pressure levels measured by use of an inverted microphone range from a minimum of -1 dB to a maximum of +2 dB greater than the 1/3-octave-band sound pressure levels measured by use of a microphone with its diaphragm fitted flush with the reflecting surface, over the frequency range up to 10 kHz.

Since the differences between inverted and flush microphone one-third - octave-band sound pressure levels in a steady-state laboratory test did not generally exceed 1 dB at frequencies less than 5 kHz, where most dominant propeller tones are situated, and were not more than 2 dB over the whole frequency range of interest (up to 10 kHz), differences between inverted-microphone and flush-microphone sound pressure levels should be negligible for measurements of propeller-driven aircraft flyover noise[10,12,13]. Hence, for the purposes of this ARP, the small differences between the sound pressure levels measured by use of flush and inverted microphones are neglected, and 6.0 dB should be subtracted from the measured sound pressure levels at all frequencies, to obtain equivalent freefield levels of the noise from propeller-driven light aircraft.

[5,10,12,13] See references in Section 6.

4.2 Measurements Over Natural Terrain, Using the Plate-Mounted Microphone Installation: When the recommended plate-mounted inverted microphone is installed flush with a natural ground surface, there will be a discontinuity in acoustic impedance at the edge, or boundary, of the plate. Theoretical analyses and experiments[9,10,13] indicate a consistent pattern of diffraction effects for a microphone inverted over the plate, resulting in different sound pressure levels from those obtained by using a flush-mounted microphone. However, the experiments have shown that such effects are less than 0.5 dB up to 2 kHz, beyond which microphone-to-plate separation effects become predominant, and the deviations from pressure-doubled become similar to those observed for the large acoustically hard surface. Consequently, for the purposes of propeller-driven light aircraft noise measurements, the small differences between sound pressure levels measured by inverted and flush systems are again neglected, and 6.0 dB should be subtracted from the measured sound pressure levels at all frequencies to obtain equivalent freefield sound pressure levels.

5. SUMMARY: To summarize the recommendations of this ARP:

5.1 To obtain pressure-doubled sound pressure levels from propeller-driven light aircraft flight noise measurements, use a half-inch-diameter pressure or random-incidence microphone inverted with its diaphragm 7(+1,-0) mm above either a hard, rigid large surface that is light in color, or a 0.4 m diameter heavy metal plate that is at least 2.5 mm thick and light in color, preferably white.

5.2 To adjust the sound pressure level spectrum so acquired to provide an approximation of the freefield spectrum of the aircraft when it is within 30 degrees of the normal to the ground surface, subtract 6.0 dB at all frequencies.

NOTE: If the systems specified in Section 3 are used to measure the noise of airplane types other than propeller-driven light aircraft, corrections will have to be applied which are outside the scope of this ARP.

6. REFERENCES:

1. "Acoustic effects produced by a reflecting plane." Society of Automotive Engineers, Aerospace Information Report, AIR 1327 (January 1976).

2. "Practical methods to obtain free-field sound pressure levels from acoustical measurements over ground surfaces." Society of Automotive Engineers, Aerospace Information Report, AIR 1672B (Rev. June 1983).

3. M. J. T. Smith, "International Aircraft Noise Measurement Procedures: Expensive Acquisition of Poor Quality Data." American Institute of Aeronautics and Astronautics, Paper 77-1371 (1977).

[9,10,13] See references in Section 6.

6. REFERENCES: (Continued)

4. W. Dobrzynski, "Interferenzwirkung durch Bodenreflexion bei fluglarmmessungen an propeller-flugzeugen." German Institute for Aerospace Research and Development (DFVLR), Report FB-81-28 (August 1981).

5. W. L. Willshire and P. A. Nystrom, "Investigation of Effects of Microphone Position and Orientation on Near-Ground Noise Measurements." NASA Technical Paper TP-2004 (April 1982).

6. H. Heller, et al, "Field evaluation of the newly proposed ICAO Annex 16 takeoff noise certification procedure for propeller-driven aeroplanes not exceeding 5700 kg." DFVLR Report IB-128-82-9 (December 1982).

7. R. E. Cadoux, "Further report on the use of alternative microphone heights for aircraft noise measurement." British Aerospace (Weybridge), Acoustics Report 685 (March 1984).

8. B. N. Shivashankara and G. W. Stubbs, "Ground plane microphone installation for measurement of aircraft flyover noise." American Institute of Aeronautics and Astronautics, Paper AIAA 84-2353 (October 1984).

9. R. C. Payne and G. F. Miller, "A theoretical appraisal of the use of ground-plane microphones for aircraft noise measurement." National Physical Laboratory (England), Acoustics Report Ac 103 (December 1984).

10. R. E. Cadoux, "Summary of Rolls-Royce results for Navajo and HS-125 Hucknall tests on microphone height effects." British Aerospace (Weybridge), Acoustic Memo 775 (January 1985).

11. R. E.Cadoux, "Use of ground microphones for noise certification measurements on light propeller-driven aircraft." British Aerospace (Weybridge), Acoustic Memo 773 (March 1985).

12. R. C. Payne, "An experimental appraisal of the use of ground-plane microphones for aircraft noise measurement." National Physical Laboratory (England), Acoustics Report Ac 104 (August 1985).

13. M. J. T. Smith, "Aircraft noise measurement - alternatives to the standard 1.2 metres microphone height." American Institute of Aeronautics and Astronautics, Paper 86-1960 (1986).

14. Report of First Meeting of Committee on Aviation Environmental Protection (CAEP), Working Paper No.97, ICAO, Montreal 9th-20th June 1986.

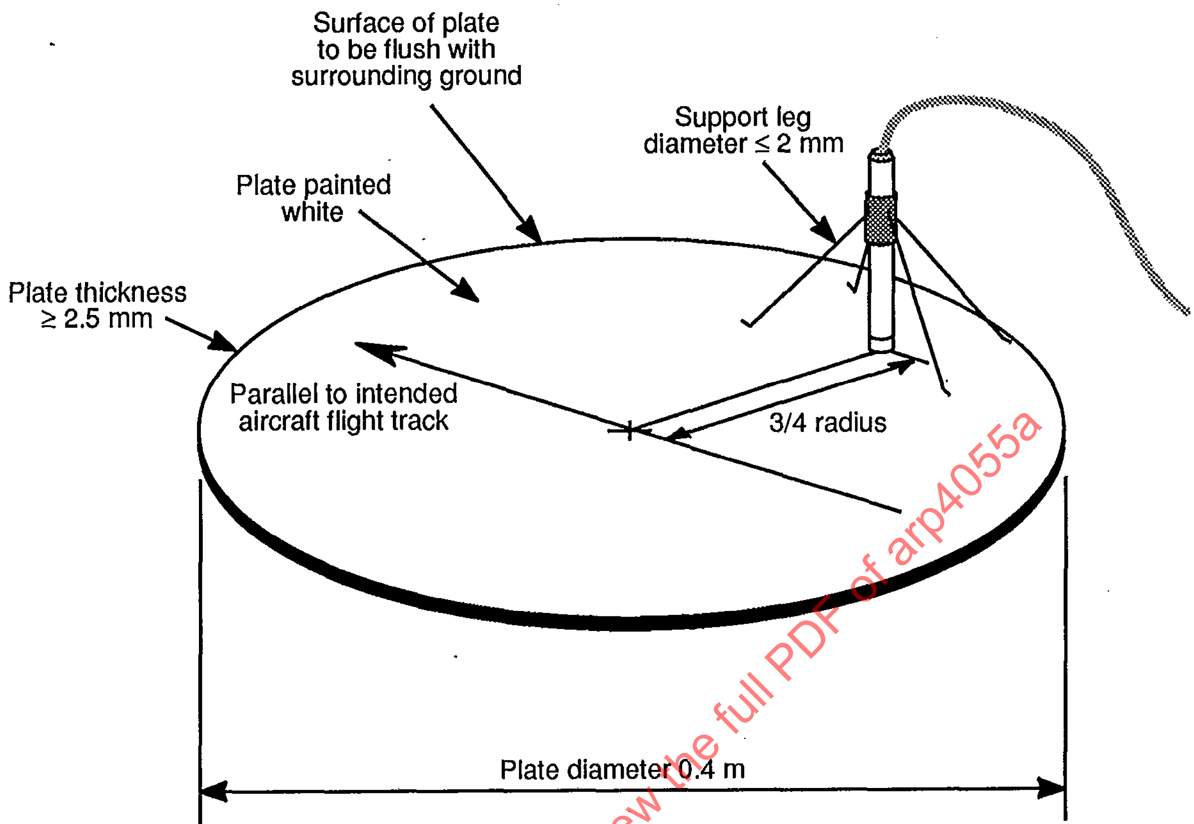

FIGURE 1 - Recommended configuration for measurements of sound pressure levels over acoustically soft ground surface with half-inch-diameter pressure microphone inverted over metal plate.

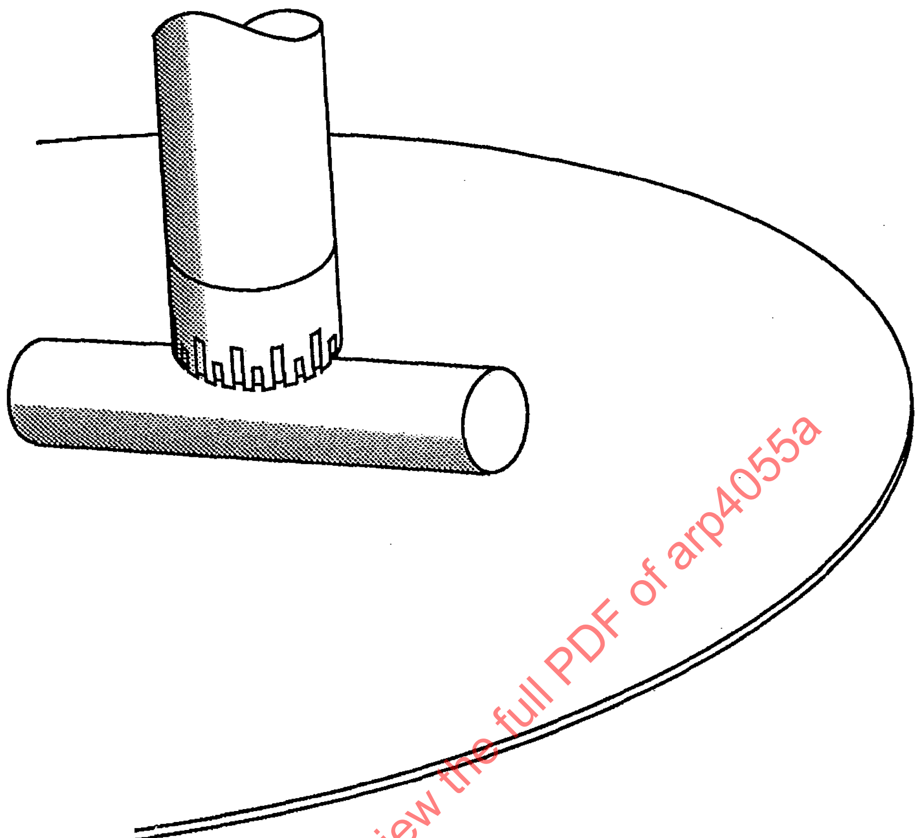

FIGURE 2 - Illustration of the use of slip/bar gauge system to set the gap between inverted microphone and base-plate, where the nominal grid-outer-surface-to-diaphragm dimension is 1.1 mm.

Prepared by

SAE COMMITTEE A-21,
AIRCRAFT NOISE

APPENDIX A

BACKGROUND INFORMATION ON GROUND-REFLECTION EFFECTS IN AIRCRAFT NOISE MEASUREMENT

The three illustrations contained in this Appendix elaborate upon some of the ground reflection interference effects referred to in the main body of the ARP.

A1 The magnitude of interference effects in the measurement of noise from propeller-driven aircraft is illustrated in Fig. A1. This shows comparisons between one-third - octave-band sound pressure levels measured by use of a microphone at a height of 1.2 m above ground, and a microphone near the ground surface.

In Fig. 1A(a), for a 2-bladed propeller, the sound pressure levels at the fundamental and second overtone of the propeller blade passing frequency were significantly lower when obtained by use of a microphone at 1.2 m than those obtained by use of a ground microphone, as a direct result of ground reflection effects.

In Fig. 1A(b), an example for a 4-bladed propeller, sound pressure levels from the 1.2 m high microphone were significantly lower at the first and second propeller blade overtones, again as a result of ground reflection effects.

If the bandwidth of the frequency analyzer used in the above analyses had been less than one-third of an octave, ground reflection effects would have caused even larger observed differences between the sound pressure levels measured at 1.2 m and near ground.

A2 Figure A2 (from Ref. 5) illustrates the effect of varying the separation between an "inverted" microphone and a hard surface, under steady-state laboratory conditions, for sound waves at normal incidence to the surface (i.e., corresponding to aircraft "overhead" in a flight test). The interference effects are seen to increase in frequency as the separation is reduced, with a "resonance" amplification being observed when the separation between the microphone diaphragm and the surface falls below 7 mm.

A3 Figure A3 (from Ref. 5) illustrates the steady-state laboratory comparison between measurements taken with a microphone mounted with its diaphragm flush in a reflecting surface and an "inverted" microphone with a 6.35 mm separation between its diaphragm and the same reflecting surface. Although the inverted system exhibited one amplification greater than 2 dB at one of the frequencies and incidence angles tested, the same test series examined a range of separations, leading to the conclusion that a 7 mm gap will limit any amplifications to less than 2 dB. In fact, in over 90% of the frequency/angular combinations possible within the 30 degree-to-the-normal-to-the-ground-surface within the scope of this ARP, the deviations from pressure-doubling due to resonance or interference effects will be less than 1 dB.